CHAPTER 1

INTRODUCTION

1.1 Overview

The power quality (PQ) problems in power distribution systems are not new, but only recently the effects of these problems have gained public awareness. Advances in semiconductor device technology have fuelled a revolution in power electronics over the past decade, and there are indications that this trend will continue [1]. However these power equipments which include adjustable-speed motor drives (ASDs), electronic power supplies, direct current (DC) motor drives, battery chargers, electronic ballasts are responsible for the rise in related PQ problems [2]-[4]. These nonlinear loads are constructed by nonlinear devices, in which the current is not proportional to the applied voltage. A simple circuit as shown in Figure 1.1 illustrates the concept of current distortion. In this case, a sinusoidal voltage is applied to a simple nonlinear resistor in which the voltage and current vary according to the curve shown. While the voltage is perfectly sinusoidal, the resulting current is distorted.

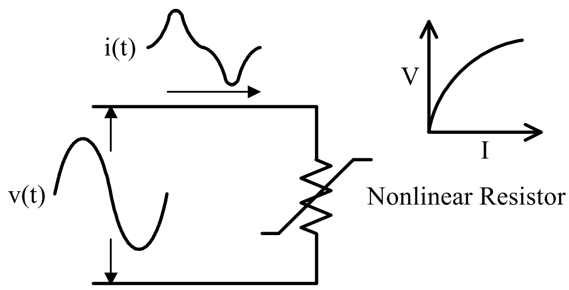

Figure 1.1 Current distortion caused by nonlinear resistance

Nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the point of common coupling (PCC). These harmonic currents can interact adversely with a wide range of power system equipment, most notably capacitors, transformers, and motors, causing additional losses, overheating, and overloading [2]-[4].

There are set of conventional solutions to the harmonic distortion problems which have existed for a long time. The passive filtering is the simplest conventional solution to mitigate the harmonic distortion [5]-[7]. Although simple, these conventional solutions that use passive elements do not always respond correctly to the dynamics of the power distribution systems [8]. Over the years, these passive filters have developed to high level of sophistication. Some even tuned to bypass specific harmonic frequencies. However, the use of passive elements at high power level makes the filter heavy and bulky. Moreover, the passive filters are known to cause resonance, thus affecting the stability of the power distribution systems [9]. As the regulatory requirements become more stringent, the passive filters might not be able to meet future revisions of a particular Standard.

Remarkable progress in power electronics had spurred interest in active power filter (APF) for harmonic distortion mitigation [10]-[15]. The basic principle of APF is to utilise power electronics technologies to produce currents components that cancel the harmonic currents from the nonlinear loads [10]. Previously, majority of controllers developed for APF are based on analogue circuits [11], [12]. As a result, the APF is inherently subjected to signal drift. Digital controller using digital signal processor (DSP) or microprocessor is preferable, primarily due to its flexibility and immunity to noise signals [13]-[15]. However it is known that using digital methods, the high order harmonics are not filtered effectively. This is due to the hardware limitation of sampling rate in real-time application [15]. Moreover, the utilisation of fast switching transistors (i.e. IGBT) in APF application causes switching frequency noise to appear in the compensated source current. This switching frequency noise requires additional filtering to prevent interference with other sensitive equipments.

The idea of hybrid APF has been proposed by several researchers [16]-[18]. In this scheme, a low cost passive high-pass filter (HPF) is used in addition to the conventional APF. The harmonics filtering task is divided between the two filters. The APF cancels the lower order harmonics, while the HPF filters the higher order harmonics. The main objective of hybrid APF, therefore is to improve the filtering performance of high-order harmonics while providing a cost-effective low order harmonics mitigation.

Recently, there is an increasing concern about the environment. The need to generate pollution-free energy has triggered considerable effort toward renewable energy (RE). RE sources such as sunlight, wind, flowing water and biomass offer the promise of clean and abundant energy [19]-[21]. They do not generate any greenhouse gases and are inexhaustible [22]. Solar energy, in particular, is especially attractive in a sunshine country like Malaysia. This energy is in DC form from photovoltaic (PV) arrays. It is converted into a more convenient alternating current (AC) power through an inverter system. Efforts have been made to combine the APF with PV array [23]-[25]. However, it appears that no attempt has been made to combine a hybrid APF with PV array.

1.2 Objective of Research

The objective of the research is two-fold: (1) to propose a new variation of hybrid APF topology with PV application. (2) to propose a simple current reference estimation method for the proposed topology.

To achieve the first objective, this research proposes a hybrid APF topology for a single-phase system, connected to a DC source that represents the PV array. The topology is unique because it effectively filters harmonic currents of low and high frequencies to obtain sinusoidal source current. Furthermore, it simultaneously supplies the power from the PV array to the load.

For the second objective, this research proposes the application of the extension instantaneous reactive-power (p-q) theorem to estimate the compensation current reference. Although the estimation of current reference based on extension p-q theorem is not new [24]-[26], this approach has not yet being applied to a single-phase hybrid APF system involving passive HPF, shunt APF and a PV array. Using the extension p-q theorem, the resulting equations for the current reference is simpler compared with the conventional p-q theorem presented in [27]. This will lead to more efficient digital controller implementation using DSP.

1.3 Methodology of Research

In the elaboration of the research, a harmonic analysis of source current distortion has been carried out. It has featured a nonlinear full-bridge diode rectifier with DC smoothing capacitor and resistive load as a harmonic currents source. The time domain simulation is performed using MATLAB/Simulink simulation package. Afterwards, an extensive computer simulation involving the power circuit of the shunt APF, passive HPF, a DC source that represents the PV array, current reference estimation based on extension p-q theorem, phase-lock loop (PLL) circuit and fixed-band hysteresis current controller is carried out.

Once satisfactory simulation results are obtained, the proposed topology is tested in the laboratory with an experimental prototype. The prototype is designed to compensate the distorted current produced by nonlinear load, as well as simultaneously supplies the power from the PV array to the load. The proposed algorithm and control system are implemented using a dSPACE DS1104 DSP controller board.

Although the original work is intended to include the PV array, the experimental set-up using PV array is not possible due to facility and time constraints. However, the PV array can be adequately replaced with a DC source. This is because the PV array is fundamentally a DC source that produces electricity in DC form.

Finally, a harmonic analysis is carried out to validate the filtering performance of the proposed hybrid APF in comparison to a basic shunt APF. The experimental results are analyzed and compared with the results obtained from the computer simulation.

1.4 Thesis Organisation

This thesis consists of this introductory chapter and six other chapters arranged as follows:

Chapter 2 covers the literature review and a brief discussion of harmonic distortion problems, conventional mitigation methods using passive filters and improved mitigation methods using APF approaches. The efforts in combining the PV array with the APF are discussed briefly. Different types of compensation reference signal estimation techniques suitable for APF applications are reviewed. A brief overview of the control strategies for APF is also provided in this chapter.

Chapter 3 presents the proposed hybrid APF topology. This chapter elucidates the topology, operating principles and control of the proposed hybrid APF and illustrates how this system can be used to supply the PV power to the load. Emphasis is given to a discussion on the design consideration of the passive HPF.

Chapter 4 concerns the system level simulation using MATLAB/Simulink. The computer simulation design is described in detail.

Chapter 5 describes the design and construction of the experimental prototype to validate the proposed hybrid APF. Detailed description of each hardware components is provided.

Chapter 6 provides the simulation and experimental results. Comparison between the simulation and experimental results is discussed in detail. A harmonic analysis is carried out to evaluate the filtering performance of the proposed hybrid APF in comparison to a basic shunt APF.

Chapter 7 summarises the research undertaken and highlights the contribution of this thesis. It offers recommendations for further research.